MEASUREMENT OF THE HEAT CAPACITY OF HELIUM UNDER SUPERFLUID FLOWCOND1TIONS NEAR THE LAMBDA TRANS1TION

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A proposed experiment to measure the heat capacity of helium under superfluid flow condition near the lambda transition is discussed, This experiment would clarify the role of the superfluid density depression versus the role of the intrinsic critical velocity, in the description of the property of helium.

Recently, there are considerable interests in the nature of the lambda transition under superfluid flow conditions. Onuiki[1] has predicted that the transition becomes first order and hysteresis in the normal-superfluid interface would be observed if heat is used to created counter flow in *the* superfluid phase. Also predicted is that the transition temperature T_λ would be shifted under a heat flux Q. The shift is given by $\Delta T_\lambda/T_\lambda$ - $(Q/Q_0)^x$ *where x=0.74, and Q_0 -13000 W/cm^2. Most recently, the renormalization group theory calculation of Haussmann and Dohm[2] predicted a similar shift with a slightly smaller Q_0.

Several experiments have already studied the transition under heat flow, Leiderer and Pobell[3] and later Bhagat and Lasken[4] have measured the temperature in the fluid under heat flow condition, As T_λ is approached, a sudden temperature change was interpreted by Bhagat and Lasken as the location of T_λ under a counter flow current. Recently Duncan, Ahlers and Steinberg[5] (DAS) have extended these measurements to a reduced temperature of 10^{-8} with the use of a high resolution thermometer. As shown in Fig. 1, there are significant differences between experiments and theories.

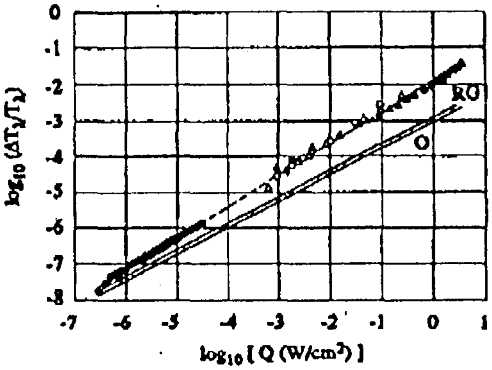

Figure 1. The apparent shift in T_λ under a heat flux or an equivalent v_s. The data are: A - Clew and Reppy, A - Leiderer and Pobell, 0- Bhagat and Lasken, ● - Duncan, Ahlers and Steinberg, The solid lines labeled RG and O are the predictions of Haussmann and Dohm, and that of Onuiki respectively. The dashed line is a best fit to the data.

It was suggested that the shift in T_λ is caused by the depression of the superfluid density ρ_s under superfluid flow condition,

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The depression of ρ_s is based on sound theoretical arguments that the extra degree of freedom of counter flow in the two-fluid model, must be reflected as a dependence of the intrinsic properties of helium on the counterflow velocity. Hess[6] has already observed this effect far away from T_λ. The question is whether there is any independent evidence that ρ_s is depressed near what DAS considered to be T_λ. Some information to the answer of this question are contained in the experiment of Clew and Reppy[7], where the angular momentum of a superfluid gyroscope is measured near T_λ. Due macroscopic quantization, the superfluid velocity v_s is constant as the temperature is varied. Thus as T_λ is approached, the angular momentum is proportional to ρ_s, until a critical point is reached where v_s spontaneously decays to a lower value, and the angular momentum decreases abruptly, This point was interpreted as the temperature where the intrinsic critical velocity was exceeded. The Langer and Fisher theory[8] attributes this effect to the creation of vortex-rings through thermal activation, Subsequent observation of the decay characteristics of v_s by Kukich, Henkel and Reppy[9] confirmed the thermal activation origin of the process. Based on these data, there is no observable depression in ρ_s, up to the point where the intrinsic critical velocity V_c is exceeded. To compare this experiment with the experiment using counter flow, we have converted v_c to an equivalent heat flux Q_c, using the two fluid model ($Q_c = sT\rho_s v_c$). The data are shown by the solid triangle in Figure 1, The data coincide with those of Bhagat and Lasken, and Leiderer and Pobell, suggesting that their observations are obtained at a point whet-e ps is finite, and thus are better explained by the intrinsic critical velocity rather than the depression of ρ_s. The data of DAS are obtained with a much smaller heat flux, where measurement of ρ_s does not yet exist, The proposed experiment is to measure the heat capacity under both heat flux condition and persistent current condition. The use of high resolution thermometer[10] with a resolution of 3×10^{-10} K/$\sqrt{\mathrm{Hz}}$ would allow the heat capacity to be measured to 0.2% in the temperature range covered by DAS, with a limitation set by gravity. Any deviation of the heat capacity under superfluid flow would support the idea of ρ_s depression. A space bound experiment would then be designed to fully map out the heat capacity as a function of temperature and v_s. Such data would provide a valuable test of the renormalization goup theory which is currently being developed to cover this experimental situational.

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